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Visible/Short-Wave Infrared Earth Resource Instrument SWaP Reduction

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NASA SLI Instrument Study Requirements

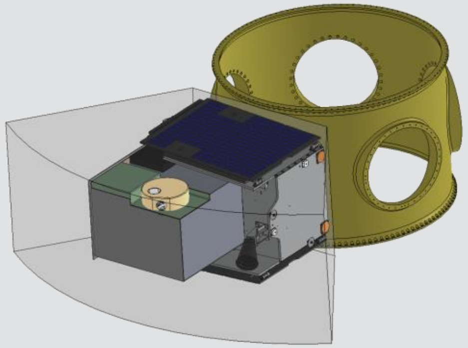
- Team SST-US was one of six companies that competed for and received NASA funding via the NASA Goddard Space Flight Center Sustained Land Imaging (SLI) Office to conduct a six month study involving small instrument conceptual designs, decisions and trades.
- The primary intent of the study was to design a much smaller instrument package which would meet the Landsat Data Continuity Mission (Landsat 8) SOW requirements and performance for the Operational Land Imager(OLI) and Thermal Infrared Sensor (TIRS):
  - NASA provided a LDCM requirements spreadsheet and performance values and required:
    - Radiometric math models and analysis including SNR, dynamic range, absolute radiometric uncertainty and stability, pixel-to-pixel uniformity, optical design
    - Performance analysis including relative edge response, geometric and spatial error budget
    - Spacecraft assumptions for both absolute LOS and relative LOS
    - Stray light analysis for both diffused/scattered and ghosting/coherent stray light
    - Relative spectral and out of band responses
    - End of life degradation performance margin analysis.

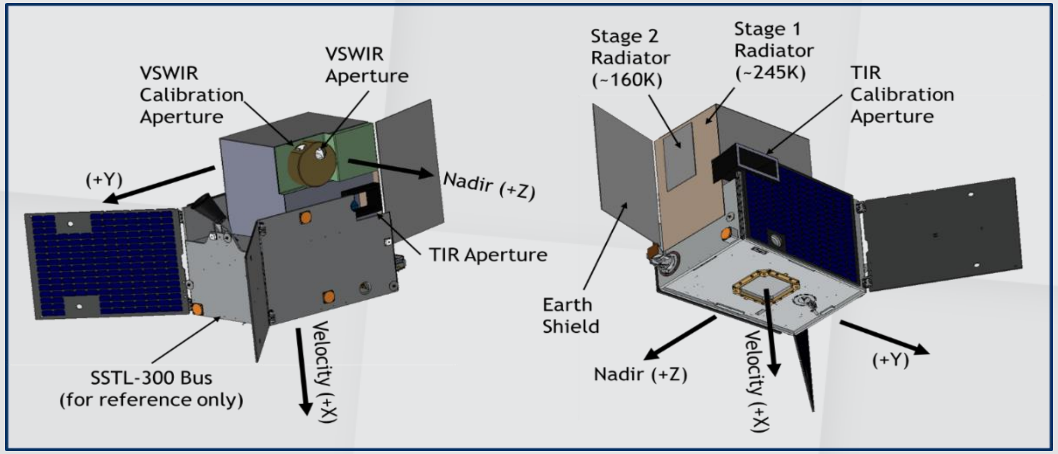
ALL THIS AND FIT WITHIN A 50CM CUBE, 50W POWER, AND 50KG MASS

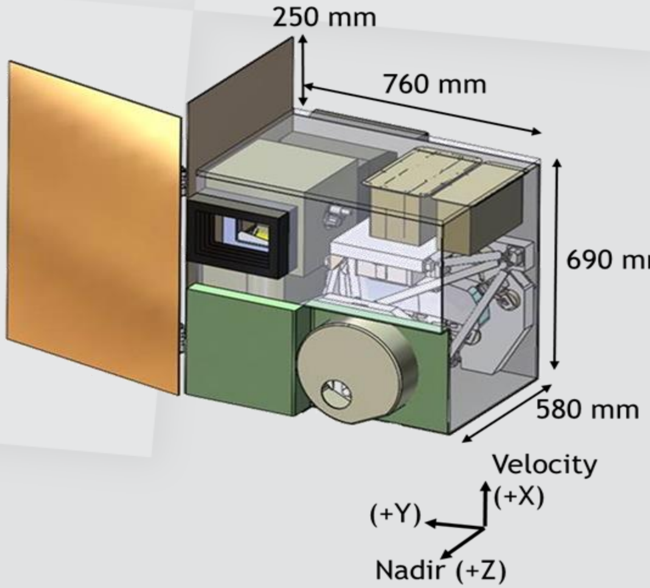
Introduction

- Started from the two existing instruments (Surrey TrueColor and SDL TIR)
  - Investigated looking at combining the telescopes and focal planes into a single aperture instrument
    - Became too large and calibration became complicated
- Continued with two telescopes (preferred optical design)
  - TIR instrument being discussed in next presentation by SDL
- Final complete instrument design :
  - Slightly exceeds requirements for dimensions, mass and power
  - But meets ESPA Grande requirements and small satellite accommodation
  - Instrument shown on SSTL-300 bus
- This talk will address our OLI-VSWIR solution

Size	.76 m x .69 m x.58 m
Volume	0.30 m^3
Mass	131 kg ~25% margin
OAP/Peak Power	162 W/ 197 W

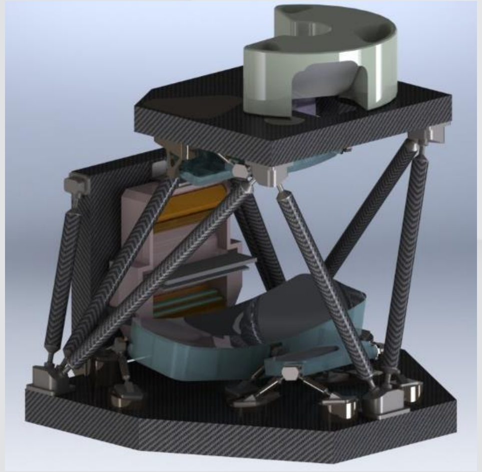


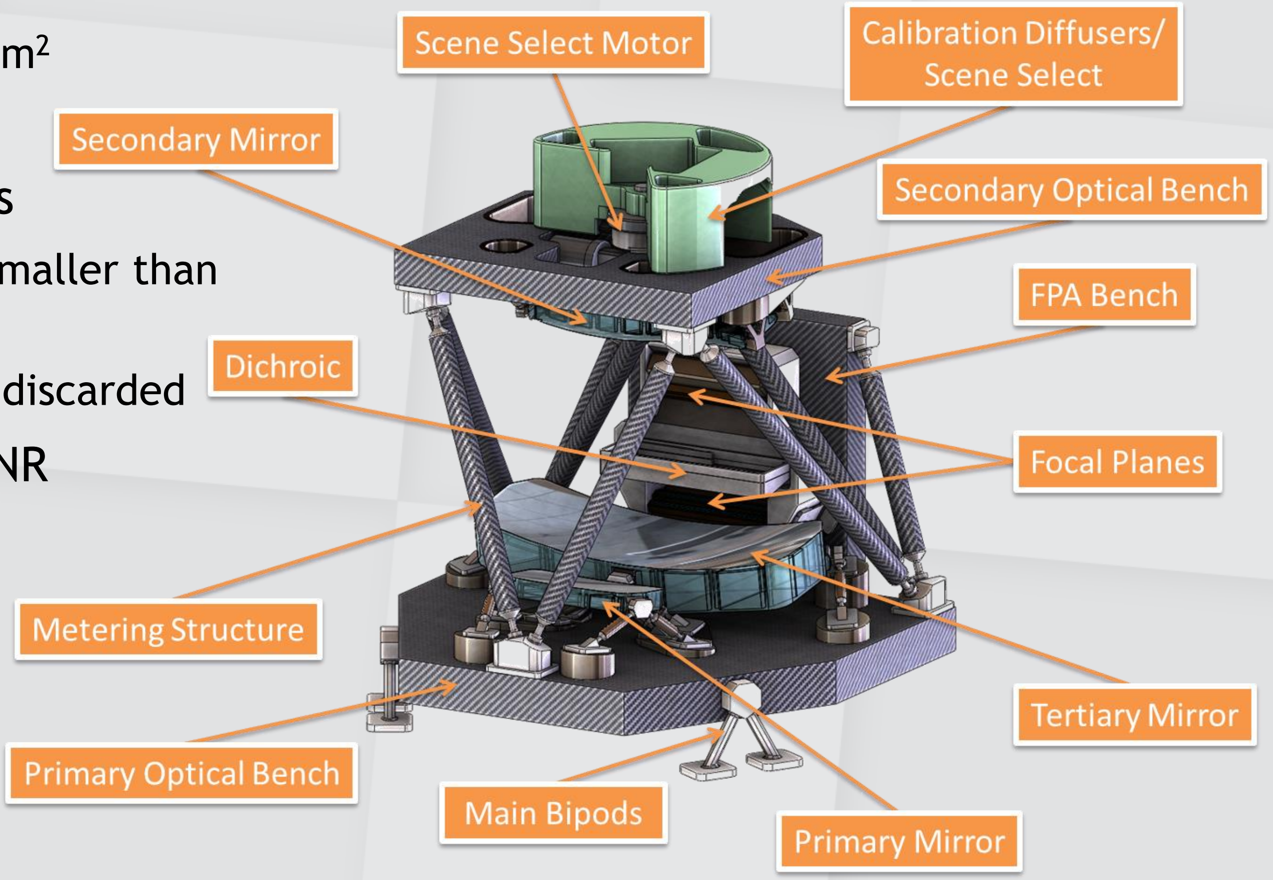




VSWIR Overview

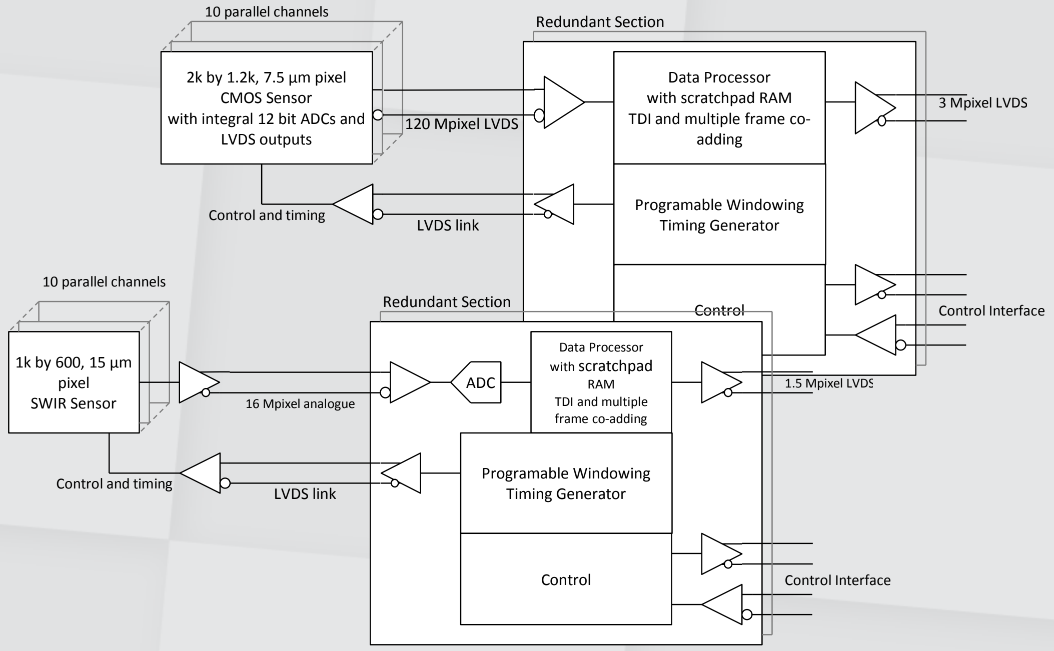
- Modified Three-Mirror Anastigmat telescope
  - Rectangular aperture 60mm x 60mm = 0.036 m^2
  - Focal Length 528.75
- Dichroic split between visible and SWIR bands
  - 2 lens telescopes (VNIR and SWIR) probably smaller than one mirror telescope
  - But 2 lenses require 2 calibration systems so discarded
- Area array detectors, using TDI to enhance SNR
  - CMOS detectors for visible bands
  - MCT for near and short-wave IR bands

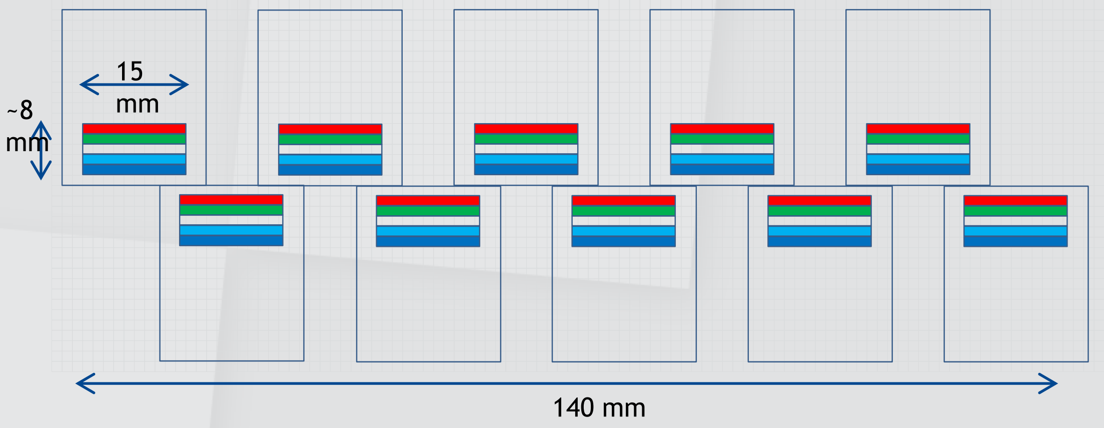




VSWIR Focal Plane(s)

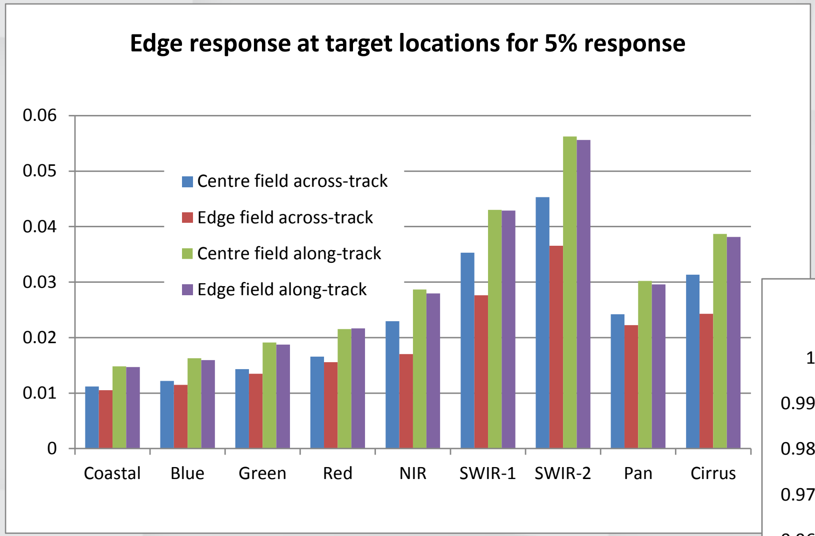
- Detectors to cover 185km swath
  - Staggered arrays help to deal with non-telecentricity (±8.6⁰ ACT beam angles)
  - SOFRADIR NGP 1024 x 600 arrays MCT SWIR arrays for 20 m GSD, 15 µm elements
  - Fairchild 2048-element x 1200+ CMOS arrays for 10 m Pan, 7.5 µm detector elements (binned 2x2 for MSI)
  - Selected detector rows used for TDI/redundancy
- Filters
  - Use "butchers block" filter assemblies to define spectral bands close to detectors mounted on FPAs
  - 5 filters for VNIR and 4 (including NIR) filters for SWIR
  - Filters will be angled ACT to reduce ACT angles of incidence
- The VNIR and SWIR focal planes are separately mounted
  - Thermally isolated to minimize parasitic inputs to SWIR



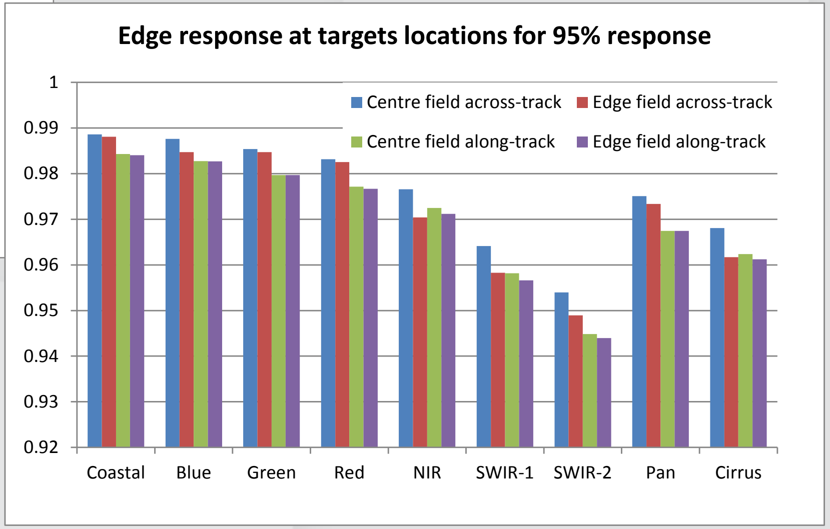


VSWIR Driving Requirements—Edge Response Performance

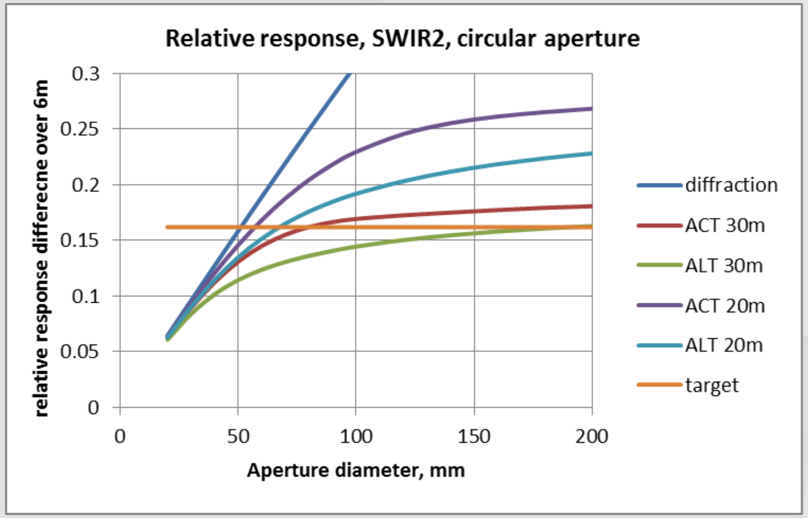
- Edge response
  - 30 m SWIR2 drives a larger aperture
  - To allow for diffraction at a smaller aperture, the IFOV is 20 m for SWIR and MSI bands, 10 m IFOV for Pan
- Requirements:
  - >0.054 m-1 for Pan
  - >0.027 m-1 other bands
  - 0.0273 ALT for SWIR-2
  - Margin in other bands



- Edge response is plotted at the LDCM <5% and >95% response half-edge extents



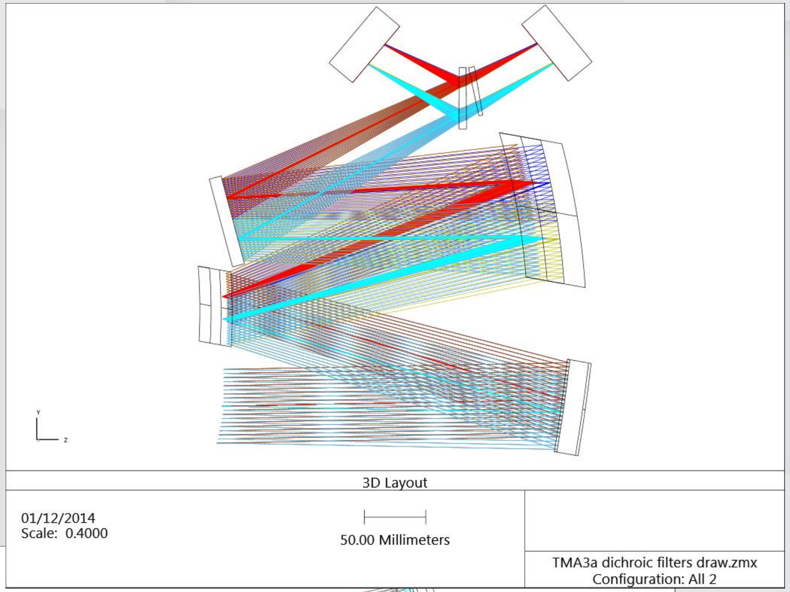
- Angular jitter not expected to have a measureable effect on edge response at <3 μradians (2 m on ground)

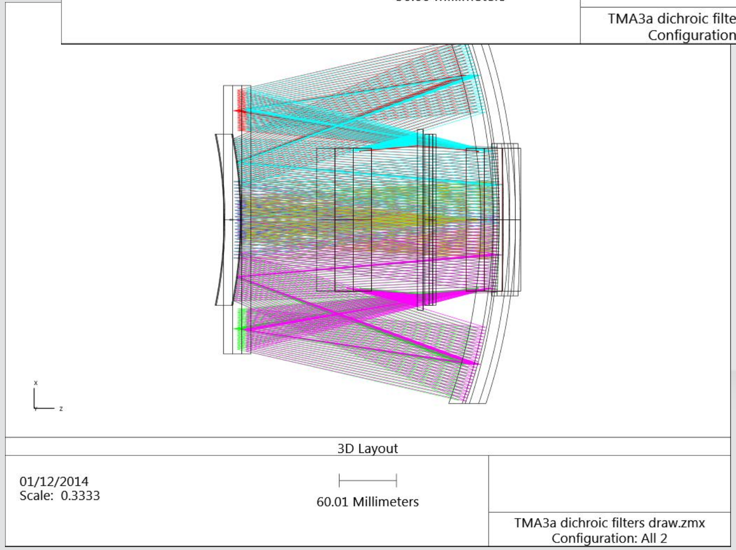


Response of SWIR2 at 30m

- **Conclusion:**
  - **Reduce GSD to fully meet edge response within a smaller package**
  - **SWIR2 requires some data sharpening processing**

VSWIR Optical Design





- TMA with a flat fold mirror after tertiary
- Covers all VSWIR spectral bands
- 3 off-axis aspheric mirrors, fold mirror and visible/SWIR dichroic
- Simple and small compared with other mirror options
  - Entrance pupil moved outside the primary mirror for calibration
  - Dichroic split between VNIR and SWIR
    - Visible reflected, SWIR transmitted
- Field angles
  - Across-track: 15^0 total for 185 km swath width
  - Along-track: 2.2^0 total to allow for staggered detector arrays
- Non-telecentric: $\pm 8.6^o$ convergence at focal plane
- Dimensions : 325 mm x 370 mm x 390 mm (ACT)
  - Excluding structure and calibration

VSWIR Stray Light Summary

- Stray light control dependent on:
  - Filter-detector reflections and cross-talk
    - Effectively eliminated by detector tilt and comb structures between filters and detectors
  - Filters have a very limited space for critical structures
    - Outer modules tilted 4^0-5^0 across-track to reduce 8^0 ACT incidence angles
  - Optical coatings and polish scatter
    - 6-layer NIR-SWIR anti-reflection coating applied to dichroic back and compensator provides <1% stray reflection and <0.5% polarization
    - All mirrors are provisionally enhanced silver with two dielectric layers.

- Design meets existing requirements

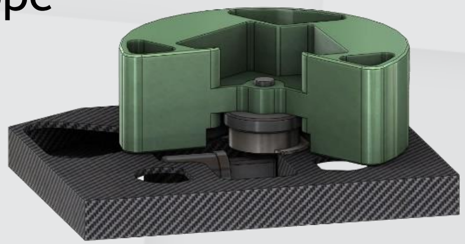
- Stray light totals for
  - 100 ppm contamination of all optics
  - Polish scatter with same Bidirectional Scatter Distribution Function (BSDF) for all surfaces calculated for a mirror with 1 nm rms roughness and a moderately pessimistic coating assumption
  - Structure scatter assuming matt black paint (5%R)

	Light rejection test summary, stray light % of Lsat				
	Coastal	Pan	NIR	Cirrus	SWIR-2
reflections & structure	0.148	0.148	0.148	0.148	0.148
surface polish	0.028	0.029	0.037	0.033	0.032
contamination	0.160	0.086	0.051	0.020	0.008
Total	**0.34**	**0.26**	**0.24**	**0.20**	**0.19**
Requirement	<0.4	<0.4	<0.4	<0.4	<0.4

	Ghosting error summary, 20 Pan pixels from bright zone				
	Coastal	Pan	NIR	Cirrus	SWIR-2
reflections & structure	0.011	0.011	0.011	0.011	0.011
surface polish	0.0920	0.0495	0.0386	0.0152	0.0059
contamination	0.0170	0.0156	0.0249	0.0158	0.0158
Total	**0.120**	**0.076**	**0.074**	**0.042**	**0.033**
Requirement	<0.47	<0.29	<0.32	<0.44	<0.45

VSWIR In-Flight Calibration System

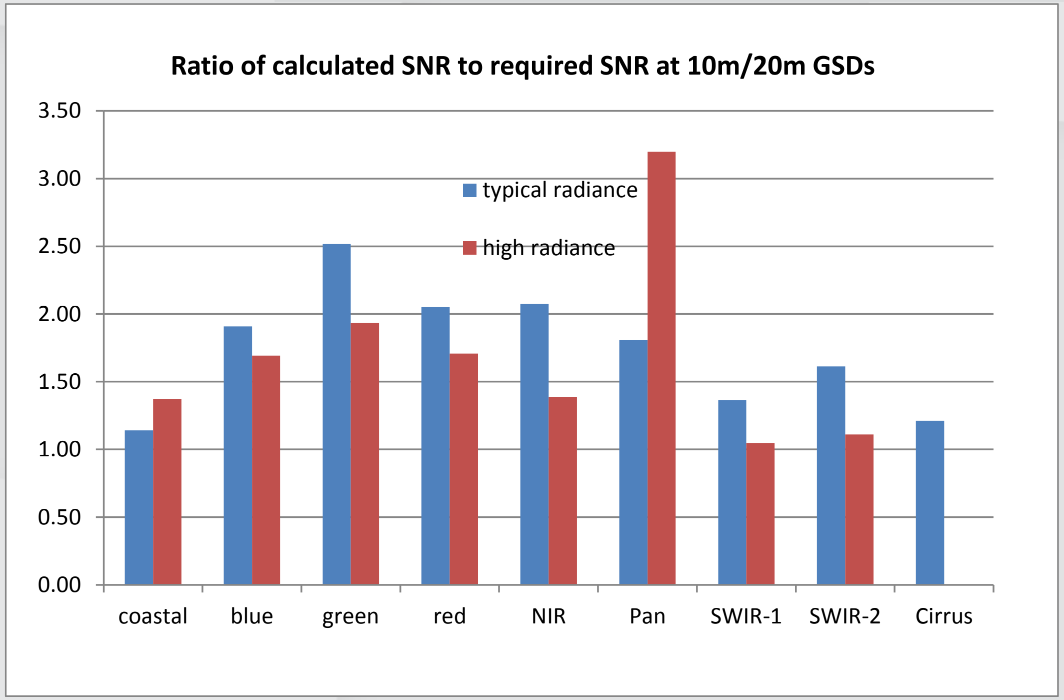
- Diffuser has a significant impact on overall system envelope
  - Requires carousel wheel mounted on the secondary bench
- Stepper motor and gearbox has three positions:
  - Nadir view
  - Primary diffused sun view
  - Redundant diffused sun view
- Looked at alternatives to diffuser calibration
  - Traded against increased reliance on vicarious calibration
  - **Thanks to Dennis Helder for his valuable help on alternative(s)**
  - **A piggy-back radiometer** was proposed :
    - An added radiometer with the same spectral bands at 5-10 times the GSD
    - Very small scale size, mass and power by factors 5-10
    - Diffusers for absolute calibration
    - Calibrates extended Earth areas for absolute reflectance
    - Main instrument calibrated using averaged Earth image data
- **Calibration analysis demonstrated compliance with OLI requirements**



VSWIR Signal-To-Noise (SNR)

- Aperture: 0.036 m^2
  - 70 mm diameter truncated to 60 mm ALT
- Native GSD: 10 m Pan, 20 m other bands
- Dwell period: 1.48 ms Pan, 2.96 ms other bands
- Digitization: 12 bits
- Thermal background for SWIR
  - SWIR cut-off wavelength: 2.4 μm
  - Temperatures:
    - SWIR detectors: 190K
    - VNIR detectors: 307K
    - Structure: 290K
    - SWIR filter block: 250K
- SNRs calculated for 10 m / 20 m GSD samples
  - Low margins for coastal and SWIR bands
- **Exceed requirements in all bands**

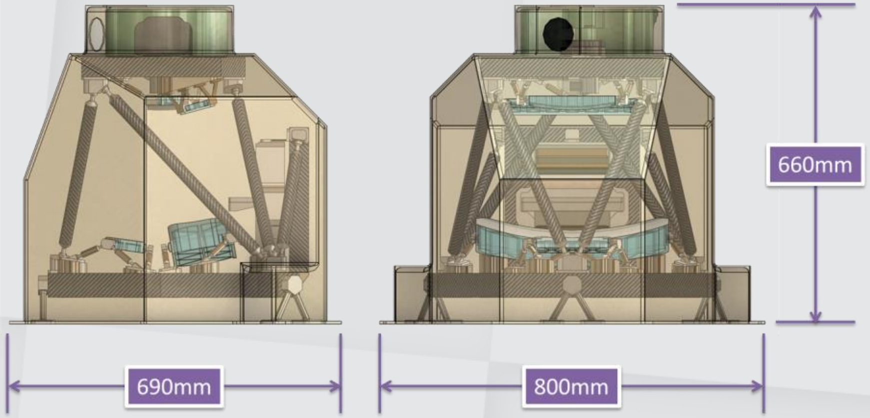
		SNR calculation					
	Signals, electrons				SNR		
Band	Thermal back-ground	Dark signal	Digit-isation noise	Read noise	Ltyp, low	Lhigh, mean	Lsat
coastal	0	83	5	30	145	390	701
blue	0	83	20	30	239	591	1061
green	0	83	28	30	241	728	1249
red	0	83	19	30	177	562	1015
NIR	0	83	18	30	152	521	715
Pan	0	10	16	30	138	711	1327
SWIR-1	117	2212	21	150	143	587	916
SWIR-2	225	2212	20	150	161	566	882
Cirrus	117	2212	7	150	64	N/A	480



VSWIR Size, Weight, and Power

Subassembly	Mass (kg)
Primary bench	14.79
Secondary bench	7.52
FPA bench	2.55
Metering structure	3.00
Calibration unit	3.55
Primary mirror	0.88
Secondary mirror	0.91
Tertiary mirror	2.77
Fold mirror	0.73
FPA	8.08
Total Mass:	**45**

- VSWIR Only Dimensions
  - 575 mm (boresight) x 560 mm x 472 mm
  - 690 mm x 660 mm x 800 mm shroud shown enclosing the VSWIR instrument



- OAP including imaging
  - FEE and detectors: 40 W
  - Thermal control: 2 W
  - Margin 20%: 8 W
  - Total: 50 W

- Peak power during calibration
  - FEE and detectors: 40 W
  - Thermal control: 2 W
  - Calibration max (stim.): 20 W
  - Margin: 20%: 13 W
  - Total: 75 W

Instrument NASA Risk Class B Analysis

- 5 Year Design Life
  - Provided NASA a Master Equipment List (MEL) with heritage column for item >TRL 6
- Redundancy and qualified hardware
  - Fully redundant payload electronics - detector, pre-amp electronics, readout electronics, instrument controller and power supply electronics, calibration motor windings
  - Multiple pathways, redundant circuits and redundant cards
    - All circuit boards will use radiation tolerant parts
    - All electronics will provide EDAC protection on any memory
    - Eliminated switches in cards due to failure possibility
  - No redundancy in the structural aspects of the telescopes, including housing, mirrors and radiators - Structural elements qualified to survive mechanical and thermal environments using high reliability assemblies; physical structure not redundant due to mass restrictions
    - No redundancy in the ROICs due to complexity it introduces
- NASA Parts Selection List (NPSL) level 2 EEE parts
  - Surrey has qualified parts procurement specification programs with high-assurance quality requirements
- Design meets Risk Class B Requirements

Conclusion

- Design meets all current LDCM OLI performance requirements
  - Some on-ground sharpening of SWIR2 might be required
  - No other accommodations for requirements are necessary
- The SWaP did not quite meet the desired NASA specification of 50cm cube, 50kg, and 50W
  - However, provided an excellent exercise in reduction of current OLI size, weight and power

	LDCM OLI	SST-US VSWIR
Dimensions	1.8m x 2.2m x 1.8m	0.575m x 0.560m x 0.472m
Mass	432 kg	45 kg
Power	139W OAP	50W OAP

- Allows accommodation on a small satellite bus for a low cost solution
  - SSTL-300 fits well for this application at a low cost price (NASA RSDO III Catalog)
- Estimated price for whole mission provided to NASA
  - Entire mission is ~1/4 cost of LDCM mission
  - VSWIR instrument is ~1/4 cost of the OLI instrument

STUDY OBJECTIVES WERE A SUCCESS!

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Thank You

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